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MAXIMUM POWER POINT TRACKING TECHNIQUES: A REVIEW

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***Abstract*: Electricity is the world's fastest-growing form of end-use energy consumption. Net electricity generation worldwide will rise by 2.3 percent per year on average till 2035. Renewables are the fastest growing source of new electricity generation. Indian Solar PV Market enjoys its Place in the solar applications following the Infusion of tracking requirements. This paper focuses on the comparative study of maximum power point tracking (MPPT) techniques. It has been analysed with different MPPT methods following the same goal of maximizing the PV system output power by tracking the maximum power on every operating condition. In this paper maximum power point tracking techniques are reviewed on basis of simplicity, convergence speed, digital or analogical implementation, sensors required, cost, range of effectiveness, and in other aspects.**

***Keywords:* MPPT, Tracking techniques, Convergence speed, Digital or analogical implementation.**

I. INTRODUCTION

A maximum power point tracking algorithm is absolutely necessary to increase the efficiency of the solar panel as it has been found that only 30-40% of energy incident is converted into electrical energy. Due to the growing demand on electricity, the limited stock and rising prices of conventional sources (such as coal and petroleum, etc.), photovoltaic (PV) energy becomes a promising alternative as it is omnipresent, freely available, environment friendly, and has less operational and maintenance costs. Therefore, the demand of PV generation systems seems to be increased for both standalone and grid-connected modes of PV systems [22], [27]. Therefore, an efficient maximum power point tracking (MPPT) technique is necessary that is expected to track the MPP at all environmental conditions and then force the PV system to operate at that MPP point.

MPP refers to PV's unique operating point delivering maximum power giving highest efficiency of array. It varies with solar insolation and temperature & needs to be monitored through tracking techniques. The operating characteristics of a solar cell consist of two regions as represented in Fig 1, the current source region and the voltage source region. In the current source region, the internal impedance of the solar cell is high and this region is located on the left side of the current-voltage curve. The voltage source region, where the internal impedance is low, is located on the right side of the current-voltage curve. As per Maximum Power Transfer Theorem, Maximum Power is delivered to load when source internal impedance matches load impedance.

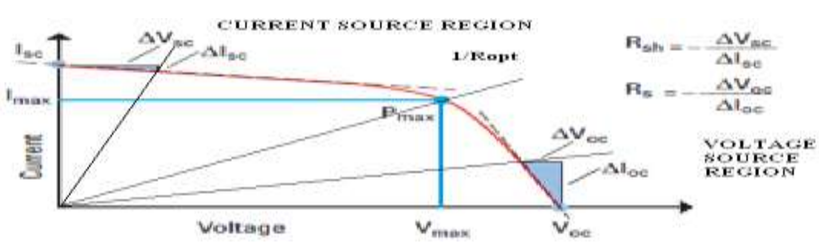

FIG 1: VOLTAGE-CURRENT & POWER-VOLTAGE CHARACTERISTICS

For determining MPP appropriate Tracker is introduced between PV system and load. It is to be designed that gives good performance, fast response, and less fluctuations. Since the efficiency of the PV is affected by the panel's irradiance and temperature which are stochastic and unpredictable. For this reason, it is not possible to connect the load directly to the PV to obtain the maximum power, so it is necessary to include a balance of system (BOS). Typically this BOS is a DC-DC converter to adjust the properties of the load. This converter has the advantage of managing the power delivered to the load. DC/DC converter is responsible for transferring maximum power from the solar PV module to the load. This acts as adjustment to match impedance of source & load. MPPT is normally operated with the use of a dc-dc converter (step up or step down). The location of the MPP is not known, but can be located, either through calculation models or by search algorithms. Fig 2 gives Block Diagram of MPPT System.

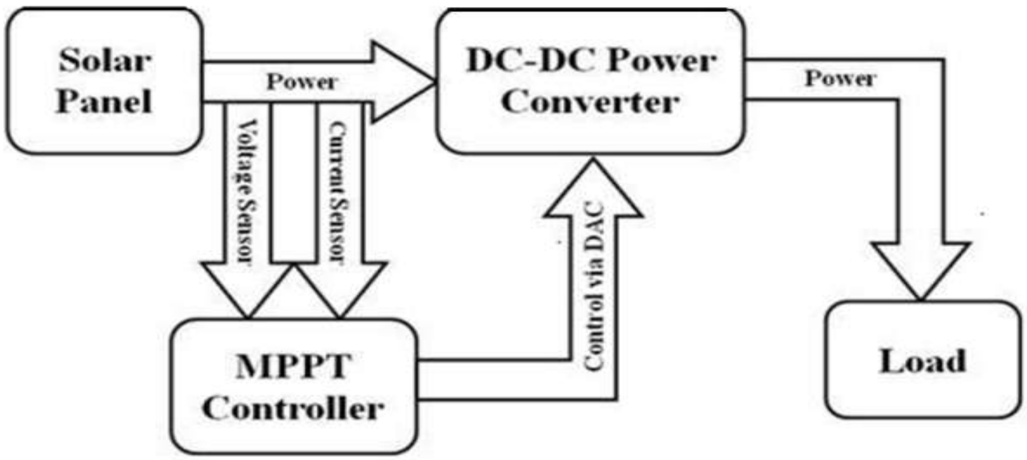

FIG 2: BLOCK DIAGRAM OF MPPT SYSTEM

The voltage across the DC-DC converter is fed to obtain an isolated load. The input–output voltage relationship for converter conduction mode is given by Duty Cycle. To compensate the parameter variations due to temperature and irradiance variations, Controller is used in the process. It makes system adaptive to changes in the environment.

II. LITERATURE REVIEW

Several MPPT techniques together with their implementation are reported in the literature [3]–[38]. Researchers always feel confused while selecting an MPPT technique for a particular application. Unfortunately, only a few techniques were available in this field including Curve fitting, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Look Up Table, One Cycle Control, Perturb and Observe, Incremental Conductance and Feedback techniques earlier that includes discussions on MPPT techniques [22]-[38] until 2007. But many new MPPT techniques such as Fuzzy logic, Artificial Neural Network, Adaptive Perturbation and Observation, Estimated perturb and perturb, Genetic Algorithm, Adaptive Neuro fuzzy and particle swarm optimization based MPPT, etc., have been reported since then illustrated in other papers [3]-[21].

It is necessary to prepare a review that includes all the efficient and effective MPPT techniques proposed before 2007 and after that until 2013. A review, comparison of the MPPT techniques on the basis of their advantages, disadvantages, control variables involved, types of circuitry, complexity of algorithm, complexity level on hardware implementation, and types of scientific and commercial application is described.

Among all the MPPT methods, Perturb & Observe (P&O) and Incremental Conductance (IC) are most commonly used because of their simple implementation and lesser time to track the maximum power point and also other economic reasons. Under suddenly changing weather conditions (irradiation level) as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiation and sometimes ends up in calculating wrong MPP [6]. However this problem is eliminated in Incremental Conductance method as the algorithm takes two samples of voltage and current to compute MPP [19]. However, instead of more efficiency the complexity of the algorithm is very high compared to the former one and hence the cost of execution increases. So we have to extenuate with a trade-off between ramification and efficiency.

It has been observed that the efficiency of the system also relies upon the converter. Generally, it is maximum for a buck analysis, then for buck-boost analysis and minimum for a boost analysis [11]. When multiple solar modules are connected in parallel, equalization of output operating points in correspondence to force displacement of input operating points of the identical operating system is evaluated. It is very elementary to carry out and has high efficiency both under stationary and time varying atmospheric conditions [23]. Among all the MPPT methods, Perturb & Observe (P&O) and Incremental Conductance are most commonly used because of their simple implementation and lesser time to track the maximum power point and also other economic reasons. Under suddenly changing weather conditions (irradiation level) as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiation and sometimes ends up in calculating wrong MPP[7]. However this problem is eliminated in Incremental Conductance method as the algorithm takes two samples of voltage and current to compute MPP. However, instead of more efficiency the complexity of the algorithm is very high compared to the former one and hence the cost of execution increases. So we have to extenuate with a trade-off between ramification and efficiency.

Since the maximum amount of solar energy, captured by the collector, is related to the accuracy for tracking sun's position [28], then a high-precision sun tracking controller should be considered. In previous years, several schemes have been proposed to improve tracking systems for following the trajectory of the sun based on orientation and tilt motion control [7], [21]. These schemes include: optimizing tilt and orientation angles of solar collectors by using geographical latitudes information [10], mathematical models [35], and tracking algorithms [13], [33-34]. In order to automatically adjust tilt and orientation angles in relation to the sun position, in the field of control engineering some approaches have been proposed based on motion control [12], [20] and signal processing by using information coming from electronic devices [13, 17].

Recently, some of the most relevant and prominent control schemes, in solar applications, have been introduced in the field of artificial intelligence which include: sun tracking systems using fuzzy control based on light-sensors, ambient temperature and electric load variations [5] fuzzy algorithms to connect domestic apparatus on either the electrical grid or a photovoltaic panel [8], [9], [18], [19], [34] prediction [24], [25], [26] and estimation of current using solar radiation [15], and hybrid systems using solar energy with technology based on genetic algorithms [14]. Although exist various approaches based on intelligent techniques, the human knowledge has been interpreted just as information coming from sensors and electronics devices. This structure is simple and allows the initial setting of network parameters to be intuitively selected. Thus by following IF–THEN rules, similar to human sense, multivariate information could be included into the fuzzy inference system.

But there exists human knowledge generated since many years ago in astronomical and physics research [30], [31], [32] that should be a powerful tool-based-knowledge. For example, the advantage of integration between fuzzy logic and neural networks, called neuro-fuzzy, is due to the learning ability of neural networks and the human-like reasoning of fuzzy logic [16]. Therefore, this scheme suggests that human knowledge could be included not only based on electronic devices information but also based on astronomical information obtained from databases and scientific knowledge accumulated through the years.

Classification of MPPT techniques [3], [4] in above surveyed papers defines control strategies of three types: indirect control, direct control, and probabilistic control. Direct control strategies can seek MPP directly by taking into account the variations of the PV panel operating points without any advanced knowledge of the PV panel characteristics. This is again of two types such as sampling methods and modulation methods. Two different control variables such as voltage, current or solar irradiance, temperature etc. are often chosen to achieve the MPPT applications. According to the variables which need to be sensed, MPPT techniques can be classified into two types, such as one-variable techniques and two-variable techniques. It is easier and cheap to implement voltage sensor whereas current sensor. The circuitry involved in MPPT techniques are of two types such as analog circuit and digital circuit. Some applications need accurate MPPT and cost is not an issue, such as, solar vehicles, industry, large-scale residential. But some systems like small residential applications, water pumping for irrigation, etc., need a simple and cheap MPPT technique. Expensive applications generally use advanced and complex circuitry because accuracy and fast response are main priorities there.

Considering the above facts, review justified that Fuzzy logic system based Intellegent or Hybrid techniques in PV give Good performances, Fast responses, No overshoot, & less Fluctuations for rapid temperature and irradiance variations. For Fuzzy

Logic Controller & Neuro- Fuzzy based Systems there is no requirement of exact PV model hence they will be considered to work upon. Fuzzy logic provides an attractive framework to work when designing a scheme for the detection of shaded Photovoltaics. The low modeling requirements and high prototyping speed of a fuzzy logic scheme, given that such consensus is lacking, are of great benefit [4].

III. TECHNIQUES COMPARISON

S.N	TECHNIQUE USED	DESCRIPTION	METHOD	VARIABLE	CKT	TUNING	COST	HARD WARE
1	Curve Fitting	Characteristics based on mathematical equations or numerical approximations using third order polynomial with roots.	Incremental Conductance	Voltage	Digital	Yes	Inexp	Simple
2	Forced Short Circuit Current	Nonlinear characteristics of PV system is modeled using mathematical equations or numerical approximations for IMPP=KSCISC	Incremental Conductance	Voltage or Current	Analog and Digital	Yes	Inexp	Simple
3	Forced Open Circuit Voltage	In this technique, roots can be calculated from the empirical relationship shown as follows for VMPP=KOCVOC	Incremental Conductance	Voltage or Current	Digital	Yes	Inexp	Simple
4	Look Up Table	MPP of a PV system is calculated before hand for each probable environmental condition and stored in the memory device of MPPT's control system.	Incremental Conductance	Voltage or Current	Analog and Digital	Yes	Inexp	Simple
5	One Cycle Control	Nonlinear MPPT control technique. It involves the use of a single-stage inverter where the output current of the inverter can be adjusted according to the voltage of the PV array so as to extract the maximum power from it.	Sampling Method	Current	Analog and Digital	Yes	Inexp	Simple
6	Differenciation dV/dt	This technique determines MPP of a PV system on solving the following: dP/dt=d(IV)/dt=IdV/dt + VdI/dt=0	Sampling Method	Voltage or Current	Digital	Yes	Exp	Complex
7	Feedback Voltage or Current	This technique is used in the system which has no battery. Without a battery, a simple controller is needed to fix the panel voltage at a constant level. Hence, a simple MPPT controller can be applied to maintain duty cycle of converter.	Sampling Method	Voltage or Current	Digital	No	Exp	Complex
8	Feedback Power with Current	Similar to above technique with variation related to dP/dI equating 0 at MPP.	Sampling Method	Voltage or Current	Digital	No	Exp	Complex
9	Feedback Power with Voltage	Similar to above technique with variation related to dP/dV equating 0 at MPP.	Sampling Method	Voltage or Current	Analog and Digital	No	Exp	Complex
10	Perturb and Observe Hill Climbing	First PV voltage and current are measured power is calculated. A small perturbation of voltage or perturbation of duty cycle is done and then compared with previous power.	Sampling Method	Voltage or Current	Analog and Digital	No	Exp	Complex

11	Increment Conductnce	For a PV system, the derivative of panel output power with its voltage is expressed as dP/dt=d (IV)/dt=I + VdI/dV=0.It is zero at MPP, positive on the left and negative on the right of MPP.	Sampling Method	Voltage or Current	Digital	No	Exp	Complex
12	Forced Oscillation	Small-signal sinusoidal is injected into the switching frequency and comparing the ac component and the average value of the panel terminal voltage.	Modulation Method	Voltage or Current	Analog	Yes	Exp	Complex
13	Ripple Correction Control	When a PV array is connected to a power converter, the switching action of the converter imposes voltage and current ripple on the PV array. These ripples are used to determine MPP.	Modulation Method	Voltage or Current	Analog	Yes	Exp	Complex
14	Estimated Perturb Perturb	EPP technique is an extended P&O method. This technique has one estimate mode between two perturb modes for irradiance-changing conditions.	Sampling Method	Voltage or Current	Analog and Digital	No	Exp	Complex
15	Intelligent Techniques	Fuzzy Logic based Artificial Neural Network Based Particle swarm optimization based	Intelligent Method	Voltage or Current	Digital	Yes	Exp	Complex
16	Hybrid MPPT Techniques	P&O-ANN hybrid MPPT tracking is possible. For strengthening ANN based MPPT technique using Genetic Algorithm (GA). Adaptive Neuro-Fuzzy inference system (ANFIS).	Sampling Method	Voltage or Current	Digital	Yes	Exp	Medium
17	DMPPT Techniques	Distributed MPPT due to orientations of PV modules in array, shadowing effects, manufacturing tolerances, nonuniformity of temperature, uneven solar irradiation and air circulation, dust and spot dirtiness.	Intelligent Method	Voltage or Current	Digital	Yes	Exp	Complex

After surveying various Research works following limitations are highlighted:

(i) In [22-38] it is described that methods relative to FOCV, FSCC, RCC, and LUT cannot regulate both input and output impedances at the same time as they are offline Indirect based techniques based on pre determined data hence online systems only need to be implemented.

(ii) The efficiency gain from MPPT is large, but the system needs to take efficiency loss by DC-DC converter into account. Systems using direct techniques cannot regulate both input and output at the same time. Also the MPPT stops its original task if the load cannot consume all the power delivered resulting in tradeoff between efficiency and the cost [5], [6].

(iii) Intelligent systems achieve good performances, less fluctuations with no overshoot if implemented properly. [3], [4]

(iv) Either MPPT tracking algorithm using different techniques or Panel Rotation techniques have been identified [4]-[37]. To obtain maximum profit of standalone or grid connected PV system both need to be studied on a collective scale if MPPT efficiency needs to be improved given by:

$$\eta_{\mathrm{MPPT}} = \frac{P_{\mathrm{PV}}}{P_{\mathrm{mpp}}} \times 100$$

where P_{PV} refers to Power produced at output of PV Panel and P_{MPP} refers to Power produced at MPP.

(v) The international PHOTON magazine proposes diagnosis for Real time PV Simulator. Different orientations of PV modules in array , shadowing effects by clouds , manufacturing tolerances, nonuniformity of ambient temperature , uneven solar irradiation and air circulation, dust and spot dirtiness (leaves, bird droppings) as studied in [9] leading to Distributed Maximum Power Point Tracking (DMPPT) need to be emphasized on.

(vi) Solar cell Configurations related to Perovskites particular type of crystalline materials need to stack upon for increasing absorption property, reducing dirt, less expensive installation & efficient working [37].

IV. RESULT AND DISCUSSION

In the fig 3, 4 and 5, graph of Current Vs Voltage, Power Vs Voltage and Maximum Power Point are plotted using Simulink Modelling in MATLAB.

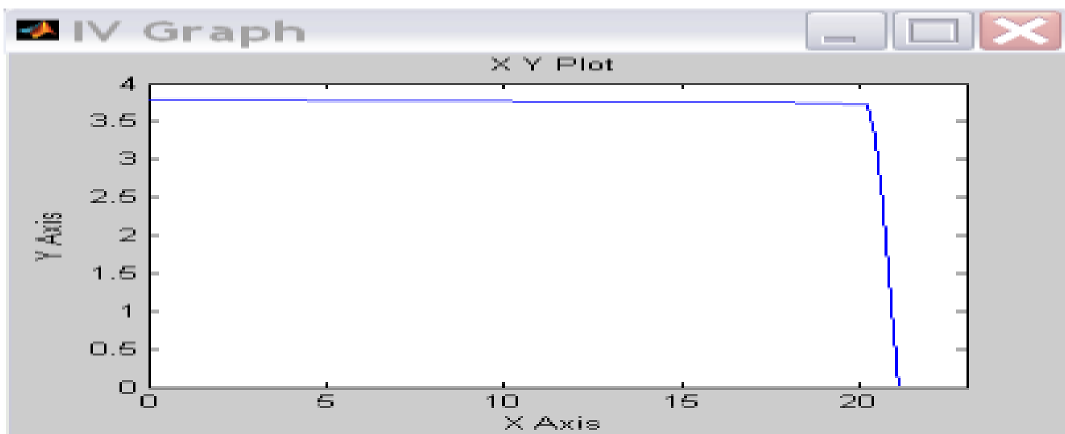

FIG 3: IV CHARACTERISTICS OF MPPT SYSTEM

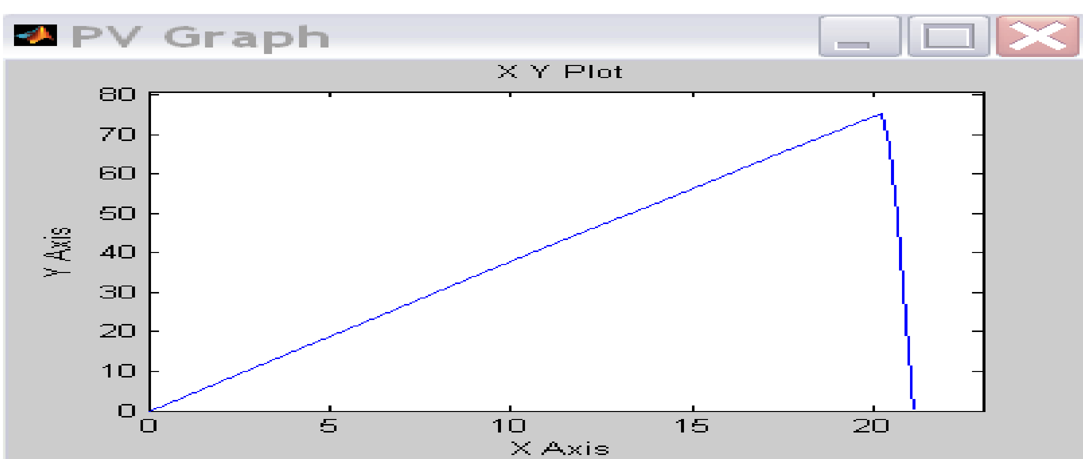

FIG 4: PV CHARACTERISTICS OF MPPT SYSTEM

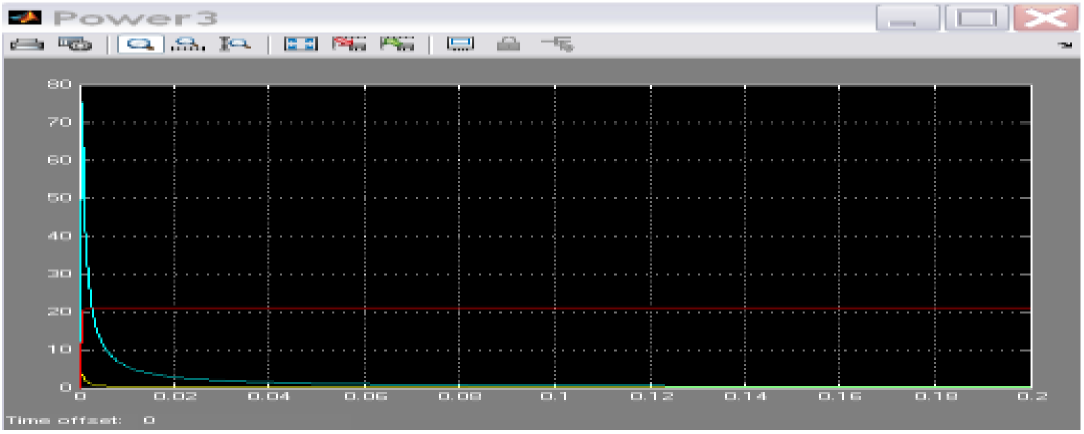

FIG 5: MPP DETERMINATION

VI. CONCLUSION

Thus comparison and results show that intellegent methods systems prove more adaptive in regulating PV outputs.

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